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Intermountain Forest and Range Experiment Station Ogden, UT 84401

General Technical Report INT-123

August 1982

dels to Estimate Revegetation Potentials of Land Surface Mined for Coal in the West

Paul E. Packer, Chester E. Jensen, Edward L. Noble, and John A. Marshall

[redacted]

MINING

REVEGETATION

$$\widehat{\text{Production}} = 0.0061896 \cdot \text{YPPR} \cdot \text{YPGS} \cdot (\text{PR})^{1.6} \cdot \begin{array}{l} \underline{\text{Kind of vegetation}} \\ 1.04368 \text{ (native)} \\ 1.17448 \text{ (introduced)} \end{array}$$

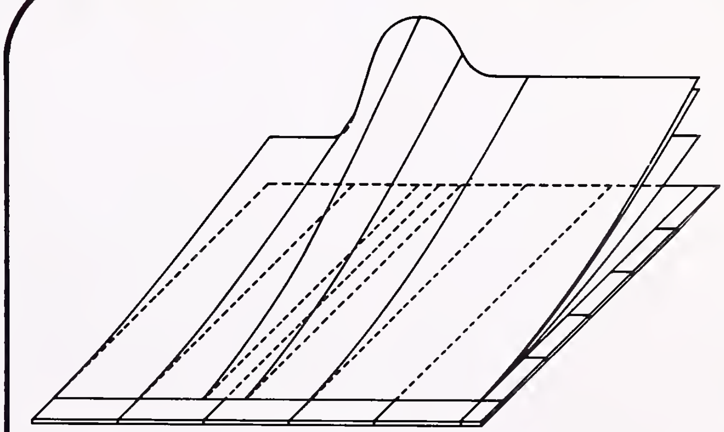
$$\text{YPPR} = e^{-\left|\frac{\frac{\text{AGE}}{7} - 1}{0.9}\right|^{4.6}}$$

If GS ≤ 85

$$\text{YPGS} = 940 + 2510 \cdot e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.16}\right|^{4}}$$

If GS > 85

$$\text{YPGS} = 2250 + 1200 \cdot e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.12}\right|^{4}}$$



RESEARCH DATA ANALYSIS

THE AUTHORS

PAUL E. PACKER, retired, served as Project Leader of the Intermountain Forest and Range Experiment Station's mine spoil reclamation research work unit. His experience as a research forester working on forest, range, and watershed rehabilitation problems in the Intermountain and Northern Rocky Mountain regions spans more than 40 years.

CHESTER E. JENSEN, retired, served as Principal Statistician for the Intermountain Forest and Range Experiment Station from 1967-80. He held the same position at the Northeastern and Central States Forest Experiment Stations prior to coming to the Intermountain Station.

EDWARD L. NOBLE, is a watershed and range management consultant. At the time of his retirement from the Forest Service in 1975, he was Branch Chief of Watershed Management for Region 4 (Intermountain Region).

JOHN A. MARSHALL, formerly systems analyst with the Intermountain Forest and Range Experiment Station, is now a computer specialist with National Forest Administration, Ketchikan, Alaska.

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RESEARCH SUMMARY

The primary objectives of this research were to develop capabilities for estimating the degree of revegetation success to be expected under a wide variety of climatic conditions, soil and spoil properties, and revegetation treatments utilizing site-specific revegetation data and information from most of the coal surface mines in the interior West. The more important study developments are these: A strong conceptual framework for evaluating the success of proposed vegetative rehabilitation efforts on areas to be surface mined. Site-specific maps to provide precipitation, growing season length, soil, and vegetation type information, critical to the evaluation system. Results of most existing surface-mine rehabilitation efforts in the interior West through 1976 were surveyed as a basis for evaluating revegetation success. Interim predictors (models) were developed, based on these survey data, for forage production and cover density potentials on undisturbed sites adjacent to the study mines and mined areas with various combinations of planting and postplanting methods and treatments designed to enhance the total rehabilitation effort for native species and introduced species.

This research shows that practical criteria for measuring revegetation success, namely, the amount of forage produced and the density of plant cover developed, are affected significantly by at least two major climatic factors (precipitation and growing season) that are not readily susceptible to alteration; by three properties of spoil materials (potassium, sodium, and pH) that are subject to limited modification through management. Revegetation success is also influenced by seven revegetation treatments, each of which provides at least two management alternatives, and by the age of the vegetation. These characteristics account for about one-half to three-fourths of the total variance in forage production and plant cover density in the prediction models.

Cover:

Mining: Spoils left in the wake of surface mining for coal in Montana.
Revegetation: A successful revegetation effort on spoils in Montana.
Research Data Analysis: *(left)* Equation for the interactive portion of one prediction model to estimate vegetative production on a mined, revegetated area. *(right)* Graphed equation for the interactive portion of one prediction model.

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Models to Estimate Revegetation Potentials of Land Surface Mined for Coal in the West

Paul E. Packer, Chester E. Jensen, Edward L. Noble, and John A. Marshall

INTRODUCTION

An emerging problem in the interior West is the adverse effect on environmental quality of spoils left in the wake of surface mining for coal (cover photo, "Mining"). Needed are criteria and guides for predicting revegetation potentials on various kinds of surface-mined land. Equally important is the need to define and prescribe revegetation treatments, as well as posttreatment management measures, for such land.

Passage and implementation of the Surface Mining Control and Reclamation Act (Public Law 95-87) and attendant regulations have placed a new emphasis on revegetation of spoil materials from coal surface mines in North Dakota, Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. Although most coal companies in the interior West are applying revegetation practices to surface mines, requirements of the new Federal Reclamation Act, in many cases, will require a reassessment and evaluation of techniques and methodologies employed in present revegetation activities. Currently, many research activities are underway to determine the best "mix" of cultural practices and plant species needed to satisfactorily revegetate disturbed land (cover photo, "Revegetation"). In the interior West not enough time has elapsed, however, since surface mine revegetation activities began to give assurance that any particular combination of revegetation methods will be successful in the long run. Consequently, mining applicants, as well as administrators granting approval to mine, can only guess on the basis of limited experience whether the required reclamation standards can be met or not.

In view of this uncertainty regarding the probability for successfully revegetating western surface coal mines, an investigation, financed jointly by the Forest Service's Surface Environment and Mining (SEAM) project, the Environmental Protection Agency, and the Fish and Wildlife Service, was begun in 1976 to identify criteria for measuring the success of revegetation, to evaluate past and ongoing revegetation efforts at most of the major surface coal mines in the interior West, and to develop a capability for predicting the probable degree of revegetation success expected on coal lands that are surface mined in the future. That investigation and its results are the subject of this paper.

INVESTIGATIVE METHODS

Criteria as set forth by the Surface Mining Control and Reclamation Act (P.L. 95-87, Section 515 (6)(19)) require coal mine operators to "establish . . . a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the native vegetation of the area; except that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved post-mining land use plan."

Accordingly, investigative methods were based on the assumption that, unless some other revegetation objective is defined, the primary goal of revegetation on surface-mined coal areas in the interior West is to establish a productive and protective cover of durable plants, consisting primarily of species adapted to and characteristic of similar, but unmined areas. It was further assumed that differences in the degree of revegetation success to date on surface-mined coal lands in the West should be related to variations in natural climatic components, changes in site-specific physical and biological characteristics, and differences in the revegetation methods used.

The degree to which plant cover is established, either in natural or revegetated stands, can be measured and evaluated in a number of ways. One of the most important measures of success in plant cover establishment is the capability of the vegetation to produce aboveground biomass for forage or some other useful purpose. Another important measure of success is the capability of the vegetation to produce ground cover for protection of the soil against the erosive forces of raindrops and surface runoff. Accordingly, the degree of success of vegetation reestablishment was measured in terms of total weight of aboveground biomass and total percent density of ground cover consisting of plant basal area and accumulated litter. Both of these measures are compatible with the legislative constraints under which mine operators must evaluate reclamation success.

With these constraints in mind and exceedingly strong agency pressures for at least an interim, but "immediate," process for evaluating proposed revegetation actions on areas to be surface mined, a study of existing mine revegetation efforts in the interior West was undertaken. The planned strategy was to provide information on forage production and cover for unmined areas to define undisturbed site potentials, and to provide similar information for comparable surface-mined sites to measure the effectiveness of vegetative rehabilitation treatments applied to date. Those combinations of treatments applied to mined sites and producing forage and cover conditions at least equivalent to the potentials on associated undisturbed sites would then be considered satisfactory for the legislative objectives above.

During the growing seasons of 1976 and 1977, data were obtained from 28 of the 34 major coal surface mines then located throughout the surface-minable coal areas of the West. These data provide information that describes important climatic features, physical and biological characteristics of each site, treatment measures employed to effect revegetation, the age of the planting on each revegetated area, and amounts of forage and ground cover density developed by both native and introduced types of vegetation on these areas. Similar information, except for the age of the vegetation, was also obtained for unmined areas near each mine that had been long-undisturbed and were characterized by predominantly native vegetation.

Information about general climatic features was obtained from tabulations of State climatic data and consisted of total annual precipitation, growing season precipitation, and length of the frost-free growing season. Climatic information of significance appears on the maps of appendix B.

Data concerned with site-specific physical and biological factors were obtained from 176 100-foot transects selected to be representative of the mined and adjacent unmined study areas. Measurements included the aspect, slope steepness, and elevation of each transect. Soil samples from the unmined areas and spoil samples from the mined and revegetated areas were obtained to a depth of 8 inches (20 cm) below the ground surface and were analyzed for texture, conductivity, nitrate nitrogen, phosphorus, potassium, sodium, calcium, magnesium, acidity (pH), sodium adsorption ratio, and saturation percentage.

Along each study transect, fifty 1-ft^2 (0.1 m^2) plots were located randomly for use in determining species composition, aboveground biomass or forage production, and plant cover density. All current growth of perennial plants within these plots was clipped to a height of one-half inch (1.27 cm) above ground, bagged by species, oven-dried for 24 hours, and weighed.

The age of each revegetated area, expressed as number of years since it was planted, and information concerning the treatments applied during and subsequent to its establishment were obtained through consultation with reclamation personnel employed at each of the mines. These treatments reflected differences in tillage, seeding methods, topsoiling, fertilizing, supplemental irrigation, mulching, and time of seeding.

All of the data obtained from 176 transects on the 28 mines studied made up the information base available for analyses.

DATA AND INFORMATION ANALYSES

Six series of analyses were made. These analyses followed multiple regression strategies for estimating forage production and plant cover density as functions of climatic components, growing medium characteristics, and revegetation treatment alternatives. The simple linear effects of independent variables on forage production and cover density were screened statistically in all combinations as a means of isolating the stronger variables for use in synthesizing final models.

Forage Production Model for Unmined Areas

Eighty-three of the 176 transects sampled during this investigation were located on unmined and otherwise long-undisturbed areas adjacent to each of the 28 mines studied. For these areas, annual precipitation amount and growing season length each added significantly ($Pr \leq 0.005$) to the regression for forage production. Soil potassium content, while not adding significantly to the regression after fitting precipitation and growing seasons, did display unusual strength in the short-to-medium length growing season and medium-to-high precipitation range; so it was retained in the model.

Strong interactions, not likely to be well represented by the simple linear additive effects initially screened, were expected to exist among these variables. Accordingly, attention was focused on the interactive effects of these three variables on forage production. Forage production was expected to increase upward concavely with increasing precipitation, to reach a peak somewhere within the broad range of growing season lengths encountered, and to increase with increasing amounts of potassium in the soil. The interactive effects of these variables were modeled under the constraints of expectation, following Jensen and Homeyer (1970, 1971) and Jensen (1973, 1976, 1979). More expressly, expected trends were adjusted to the partitioned data graphically, coordinated to arrive at the interactive relation, and, simultaneously, formulated mathematically. The resulting model was adjusted to the unmined-transect source data ($n = 83$) by least squares (zero intercept) and, under the circumstances of derivation, can only be represented as a reasonably strong hypothesis for the relation at hand. Validation and/or model improvement must be left to future studies.

The effects of precipitation, growing season, and soil potassium on forage production, as expressed by this model, are shown in figure 1. (See equation 1, appendix A.) As might be expected, figure 1 shows that low precipitation is limiting to plant growth, regardless of length of growing season (GS) or level of potassium (K). In semiarid areas of Arizona and New Mexico where precipitation (PR) varies between 5 and 10 inches (13 and 25 cm) and GS is generally in excess of 120 days, production averaged from only 100 to 250 lb/acre (112 to 280 kg/ha) on undisturbed sites.

With PR in the 10- to 15-inch (25- to 38-cm) range and GS varying from perhaps 60 to 130 days, typical of Wyoming and Montana mining sites, production generally ranged from 250 to 1,600 lb/acre (280 to 1 793 kg/ha) in the presence of relatively high K levels (260 p/m). Lesser amounts of K (150 p/m) were associated with a production drop of 100 to 300 lb/acre (112 to 336 kg/ha) within the 60- to 95-day range in GS.

North Dakota mining sites were in a slightly higher PR zone (16 to 17 inches [41 to 43 cm]) and had moderately long growing seasons (113 to 129 days). Production estimates for this region of the model were heavily affected by the more copious Wyoming and Montana data and only reached the 800- to 900-lb/acre (897- to 1 009-kg/ha) range, about 300 to 400 lb/acre (336 to 448 kg/ha) less than the average of the few observations available from the undisturbed North Dakota sites. This fact, along with the relatively high productivity rates generally accredited to the northern Great Plains, suggests the need for stronger data from that area. Note that the potassium effect here was not detectable at GS > 100 days.

A few higher elevation (7,000 to 8,000 ft [2 134 to 2 438 m]) mine sites with precipitation in the 16- to 23-inch (41- to 58-cm) range and shorter (50 to 81 days) growing seasons were sampled in northwestern Colorado. Production is generally greater there, ranging from about 1,600 to 2,100 lb/acre (1 793 to 2 354 kg/ha) for K $\geq$ 260 p/m, dropping 300 to 500 lb/acre (336 to 560 kg/ha) for K $\leq$ 150 p/m.

As a whole, this model provides our best estimates of minimum production requirements or standards against which the success of planned revegetation efforts on areas to be mined can be evaluated.

Examples of estimates of forage production made from the equation of this model for selected values of precipitation, growing season, and soil potassium are presented in table 1 to demonstrate the output format from the user-oriented computer program for this model, which is shown in appendix A.

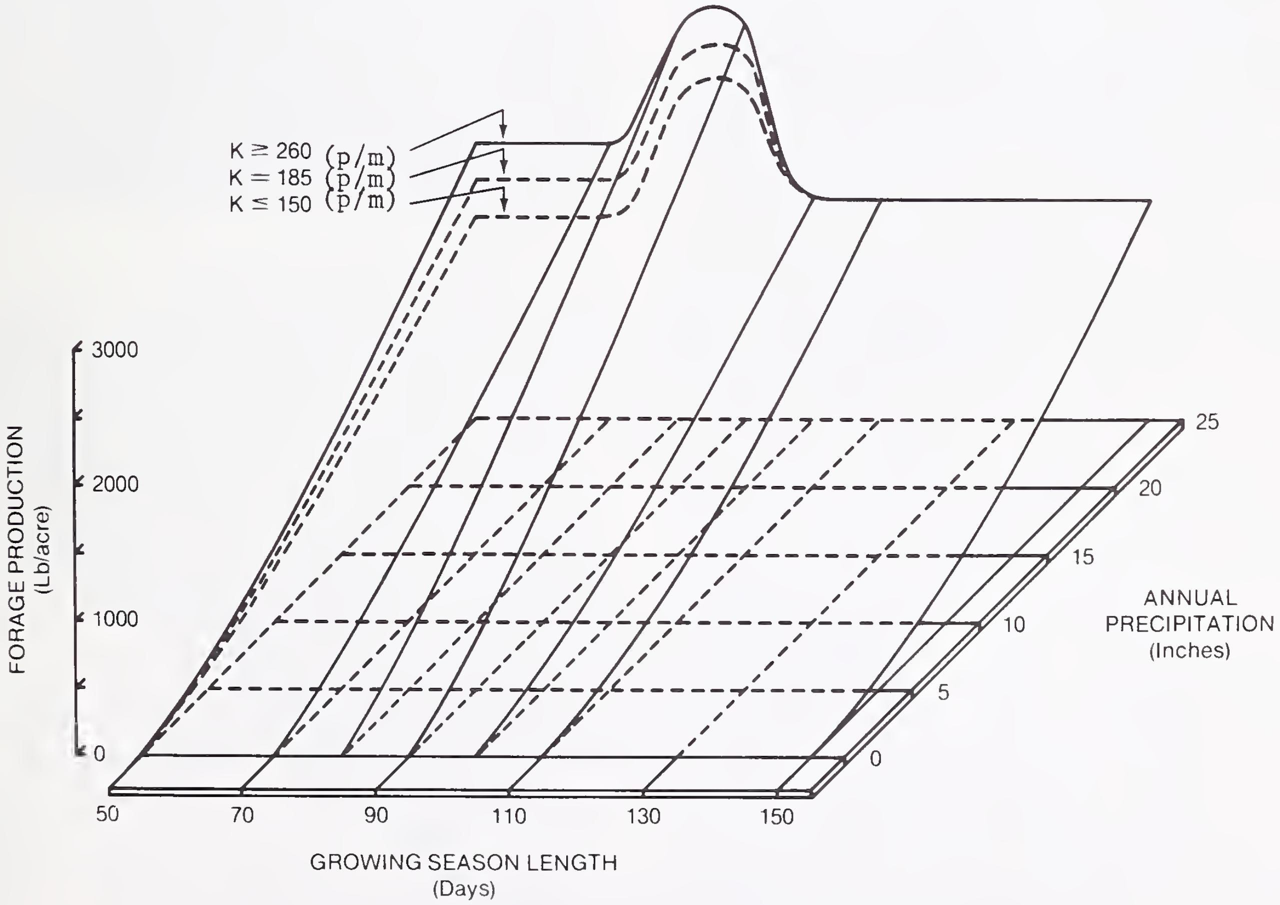

Figure 1.—Effects of annual precipitation, growing season length, and soil potassium content on forage production of unmined sites on surface mineable coal lands.

Table 1.—Effects of annual precipitation, growing season length, and soil potassium content on forage production of unmined sites on surface mineable coal lands (lbs/acre)

NO POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	155.	725.	1485.
85	333.	1313.	2487.
120	90.	644.	1608.

200 PARTS/MILLION POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	198.	927.	1897.
85	388.	1531.	2899.
120	90.	644.	1608.

400 PARTS/MILLION POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	211.	984.	2015.
85	404.	1593.	3017.
120	90.	644.	1608.

Plant Cover Density Model for Unmined Areas

Procedures for modeling the density of plant cover on unmined areas were similar to those used for forage production. Screening of linear effects again revealed that annual precipitation and length of growing season were strong variables (Pr $\leq$ 0.025) and that potassium showed strength at short-to-medium length growing seasons and medium-to-high precipitation ranges. An interactive model involving these variables was generated and fitted to data from the 83 transects located on unmined areas. Relations between plant cover density and annual precipitation, growing season length, and soil potassium content are illustrated by the response surfaces in figure 2. (See equation 2, appendix A.) As expected, this model shows that low PR is limiting to plant cover density development. This is accentuated somewhat for the generally longer and hotter growing seasons of the semiarid Southwest where, with 5 to 10 inches (13 to 25 cm) of PR, plant cover density ranges from near zero to 25 percent.

In Wyoming and Montana, at 10 to 15 inches (25 to 38 cm) of PR and 60- to 120-day growing seasons, density of cover varies from 30 to 85 percent. This full range apparently occurs in response to PR alone, where growing seasons are in excess of 100 days. In northwestern Colorado at higher elevations (7,000 to 8,000 ft [2 134 to 2 438 m]), with fewer GS (50 to 81) days and relatively high K levels ($\geq$ 260 p/m), the density of plant cover ranges from 75 to 85 percent. A decrease of 60 p/m of potassium occasions a reduction of about 10 percent in cover here.

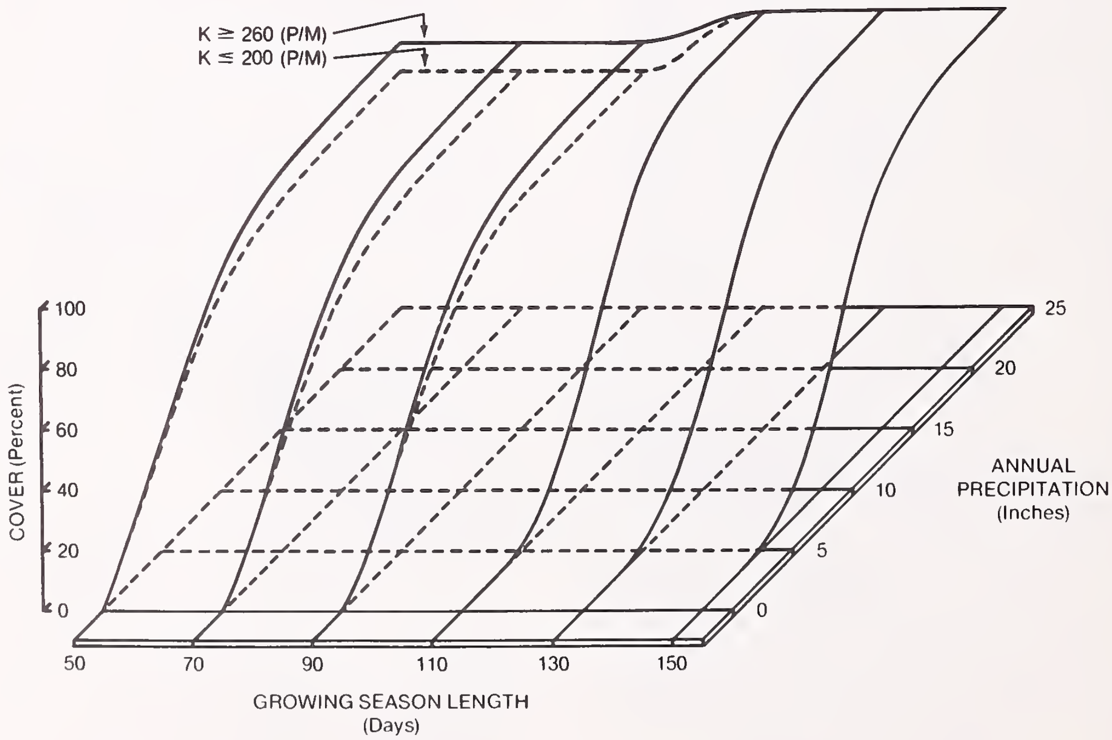

Figure 2.—Effects of annual precipitation, growing season length, and soil potassium content on vegetative cover density of unmined sites on surface mineable coal lands.

Table 2.—Effects of annual precipitation, growing season length, and soil potassium content on vetetative cover density of unmined sites on surface mineable coal lands (percent)

NO POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	34.	76.	78.
85	34.	76.	78.
120	1.	83.	98.

200 PARTS/MILLION POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	34.	76.	78.
85	34.	76.	78.
120	1.	83.	98.

400 PARTS/MILLION POTASSIUM

DAYS OF GROWING SEASON	INCHES PRECIPITATION 5	15	25
50	37.	85.	87.
85	37.	85.	87.
120	1.	83.	98.

At a PR of about 15 inches (38 cm), GS<110, and K ≥ 260 p/m, the maximum density potential of plant cover appears to be about 85 percent, with a drop to 75 percent at lower K levels (≤ 200 p/m). For GS ≥ 110 days, an almost full cover of 98 percent is reached at PR > 18 inches (46 cm). These conditions are typical of the North Dakota area. Under these conditions, potassium did not seem to be a limiting factor.

The equation for this model was used to estimate plant cover densities for selected values of annual precipitation, growing season length, and soil potassium content. Examples of these estimated plant cover densities are shown in table 2; they demonstrate the output format from the user-oriented computer program for this model, which is shown in appendix A.

This model provides estimates of plant cover density on unmined areas. These estimates can be considered as minimum requirements or standards against which the success of revegetation efforts on mined areas can be evaluated.

Forage Production Models for Mined Areas

Two models were developed to estimate forage production to be expected from revegetation of surface-mined areas. One model was generated to estimate the amounts of forage produced on revegetated areas dominated by native plant species. Another was developed to provide similar estimates where revegetated areas are dominated by introduced plant species. Each model is composed of an interactive base and a group of additive effects.

The age of the planting, the climatic components of annual precipitation and growing season length, and the potassium content of spoils (fitted in that order) added significantly (Pr ≤ 0.10) to linear regressions for forage production from both native and introduced vegetation. Subsequently, attention was focused on interactive relations between forage production and the three independent variables: age, annual precipitation, and growing season length. Forage production was expected to be convex upward over age, reaching a maximum at some point in time; to be concave upward over precipitation; and to reach a peak somewhere within the broad range of growing season lengths encountered. Expected trends were adjusted to the partitioned data graphically, coordinated to arrive at the interactive relation, and, simultaneously, formulated mathematically. The resulting model was adjusted to the mined-transect source data for native (n = 44) and introduced (n = 33) species. Under the circumstances of derivation, these models can only be represented as reasonably strong hypotheses for the relations at hand. Model validation and/or improvement must be left to future studies. The interactive portion of this model for forage production from native plant species is illustrated by the response surfaces in figure 3. (See equation 3, appendix A.)

Production for this, the interactive portion of the model, appeared to reach an upper asymptote at age-of-planting = 5 years. Production trends, as yet unadjusted for the effects of potassium, sodium, pH, and vegetative rehabilitation treatments, still closely reflected the shape of the PR effect in the production model for unmined areas and the optimum at 85 days for the GS effect still existed.

A comparable model for estimating forage production on revegetated areas dominated by introduced plant specis is identical in shape to the model for native plant species. These models of well-defined interactive effects were refitted to their respective data sets and were adopted as fixed prediction bases. The residuals from these bases were then expressed as linear additive effects of the somewhat weaker continuous variables, potassium, sodium, pH, and of the discrete (present or absent, in this case) revegetation treatment variables, tilling, seeding method, topsoiling, fertilizing, supplemental irrigation, mulching, and seeding time. The sum of the interactive and linear additive effects constitutes the estimate of production.

Selected values of annual precipitation and growing season length were utilized in the equation for the interactive model shown in figure 3. The output from this equation together with the additive effects of selected values of soil potassium, sodium, and pH content, and those of the seven revegetation treatments, provided estimates of the amounts of forage produced at 5 years of age on surface-mined areas revegetated with predominantly native species. Age of 5 years was selected for these estimates because the model revealed that biomass production from revegetation of western coal surface mines tends to reach peak development in about 5 years. Examples of these forage production estimates are presented in table 3 to demonstrate the output format from the user-oriented computer program for this model, which is shown in appendix A.

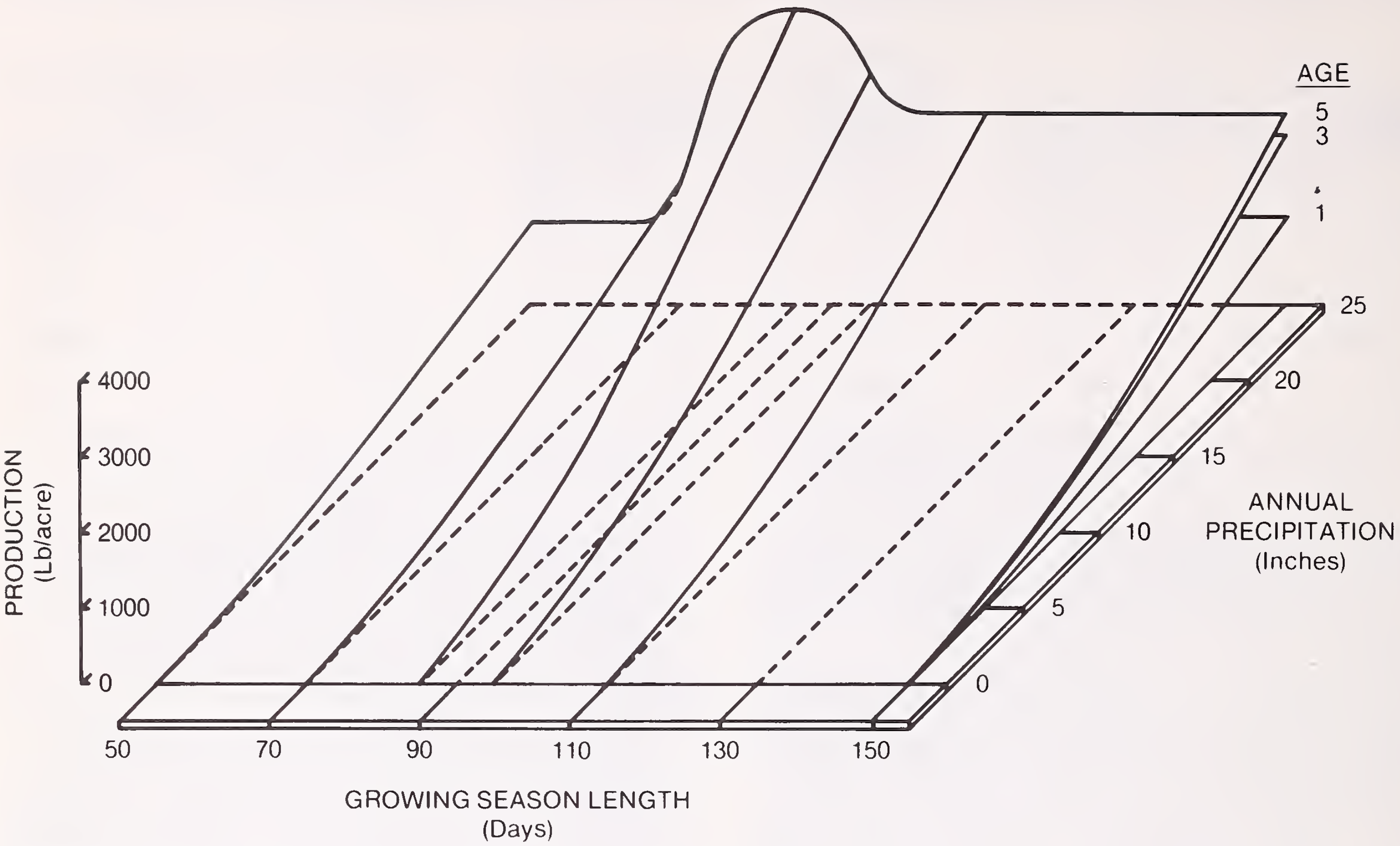

Figure 3.—Effects of annual precipitation, growing season length, and age of planting on forage production of mined and revegetated sites on coal surface mines.

Information in this sample portion of model output is divided into three blocks, each of which represents a different level of annual precipitation. In order from left to right, these levels are 5 inches (13 cm), 15 inches (38 cm), and 25 inches (64 cm). All remaining variables are identical for each of the three blocks. The growing season length is 85 days. The soil potassium content is 200 p/m. The soil sodium content (Na) is 300 meq/liter and the soil pH is 8. Each of the three blocks of the table consists of eight columns, seven of which are occupied by data from the seven revegetation treatments. The last column in each block records the dry weight of forage produced in the presence of revegetation treatments checked with the letter X. Tillage of the soil (TIL), consisting of ripping, disking, or plowing prior to seeding, is shown with an X. A blank indicates that the soil was not tilled. Drilling as a seeding method (SM) is indicated by an X, whereas broadcast seeding is represented by a blank. Addition of topsoil prior to seeding (TPS) is indicated by an X; a blank shows that no topsoil was added. An X indicates that fertilizer (FER) was added; a blank indicates that it was not. Supplemental irrigation (IRR) is indicated by an X; no irrigation is represented by a blank. Mulching (MUL) is indicated by an X, and no mulching is a blank. An X for seeding time (ST) indicates fall seeding, whereas a blank represents spring seeding.

Forage production values such as those for native species in table 3 can be compared with the appropriate forage production values for unmined areas such as those in table 1. Production values from mined and revegetated areas after 5 years of growth that are equal to or greater than the production values from similar unmined areas denote successful revegetation in relation to production of vegetation on the undisturbed areas which is assumed to reflect ecological potentials.

Similarly, estimated amounts of forage produced were generated from the interactive and additive components of the model for forage production of introduced species. These production values are 12.5 percent higher than those of native species. This is not surprising since plant species introduced for range improvement in the West generally have been selected for their exceptional hardiness and productivity characteristics.

Table 3.—Effects of climatic factors, spoil properties, and revegetation treatments on forage production of mined sites revegetated predominantly with native species (lbs/acre)

M I N E D   A R E A S
N A T I V E   S P E C I E S   P R O D U C T I O N

PR 5 GS 85 K 200 NA 300 PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	PROD PER ACRE
							72
X							85
	X						413
		X					0
			X				440
				X			107
					X		0
						X	406
X	X						426
X		X					2
X			X				454
X				X			120
X					X		0
X						X	420
	X	X					329
	X		X				781
	X			X			447
	X				X		235
	X					X	747
		X	X				357
		X		X			24
		X			X		0
		X				X	323
			X	X			475
			X		X		263
			X			X	775
				X	X		0
				X		X	441
					X	X	229
X	X	X					343
X	X		X				795
X	X			X			461
X	X				X		248
X	X					X	760
X		X	X				371
X		X		X			37
X		X			X		0
X		X				X	337
X			X	X			489
X			X		X		276
X			X			X	788
X				X	X		0
X				X		X	455
X					X	X	242
	X	X	X				698
	X	X		X			364
	X	X			X		152
	X	X				X	664
	X		X	X			816

PR 15 GS 85 K 200 NA 300 PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	PROD PER ACRE
							1469
X							1483
	X						1810
		X					1386
			X				1838
				X			1504
					X		1292
						X	1804
X	X						1823
X		X					1400
X			X				1851
X				X			1518
X					X		1305
X						X	1817
	X	X					1727
	X		X				2179
	X			X			1845
	X				X		1633
	X					X	2145
		X	X				1755
		X		X			1421
		X			X		1209
		X				X	1721
			X	X			1873
			X		X		1661
			X			X	2173 *
				X	X		1327
				X		X	1839
					X	X	1626
X	X	X					1740
X	X		X				2192
X	X			X			1858
X	X				X		1646
X	X					X	2158
X		X	X				1768
X		X		X			1435
X		X			X		1222
X		X				X	1734
X			X	X			1886
X			X		X		1674
X			X			X	2186 *
X				X	X		1340
X				X		X	1852
X					X	X	1640
	X	X	X				2096
	X	X		X			1762
	X	X			X		1550
	X	X				X	2062
	X		X	X			2214 *

PR 25 GS 85 K 200 NA 300 PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	PROD PER ACRE
							3605
X							3618
	X						3946
		X					3522
			X				3973
				X			3640
					X		3427
						X	3939
X	X						3959
X		X					3535
X			X				3987
X				X			3653
X					X		3441
X						X	3953
	X	X					3862
	X		X				4314
	X			X			3980
	X				X		3768
	X					X	4280
		X	X				3890
		X		X			3557
		X			X		3344
		X				X	3856
			X	X			4008
			X		X		3796
			X			X	4308
				X	X		3462
				X		X	3974
					X	X	3762
X	X	X					3876
X	X		X				4328
X	X			X			3994
X	X				X		3781
X	X					X	4293
X		X	X				3904
X		X		X			3570
X		X			X		3357
X		X				X	3870
X			X	X			4022
X			X		X		3809
X			X			X	4321
X				X	X		3475
X				X		X	3988
X					X	X	3775
	X	X	X				4231
	X	X		X			3897
	X	X			X		3685
	X	X				X	4197
	X		X	X			4349

Plant Cover Density Models for Mined Areas

Procedures for modeling the density of plant cover on mined areas were similar to those used to model forage production. Two interactive models were generated, one for revegetated areas predominantly characterized by native species and the other for areas dominated by introduced species. The models relate plant cover density to the amount of annual precipitation, age of the planting, and length of the growing season. These relations for mined areas revegetated with native species are illustrated by the response surfaces shown in figure 4. (See equation 4, appendix A.)

Plant cover density increased with increasing amounts of annual precipitation and with increasing age of vegetation up to about 5 years. It was also greatest at about 85 days, an intermediate growing season length. Selected values of annual precipitation and of growing season length were used in the equation for this interactive model. These, along with the additive effects of selected values of soil potassium, sodium, and pH content and of the revegetation treatments, permitted estimates of the plant cover densities expected at 5 years of age on surface-mined areas revegetated with predominantly native species.

Examples of these plant cover density estimates are presented in table 4 to demonstrate the output format from the user-oriented computer program for the model, which is shown in appendix A.

Plant cover density values, such as those in table 4, can be compared with the appropriate cover density values for unmined areas, such as those in table 2. Plant cover density values (age = 5 years) from mined and revegetated areas that are equal to or greater than those from similar unmined areas denote successful revegetation. Plant cover density development on these unmined areas is assumed to reflect ecological potentials.

Similarly, estimated plant cover density values were generated from the interactive and additive components of the plant cover density model for introduced species. These density values are 8.8 percent lower than those of native species. While introduced species are superior in producing forage native species appear able to provide better protective ground cover. Thus, both kinds of plants possess characteristics that enable them to meet requirements of the Surface Mining Control and Reclamation Act by "establishing a diverse, effective, and permanent vegetative cover" on revegetated coal mine spoils in the Western United States.

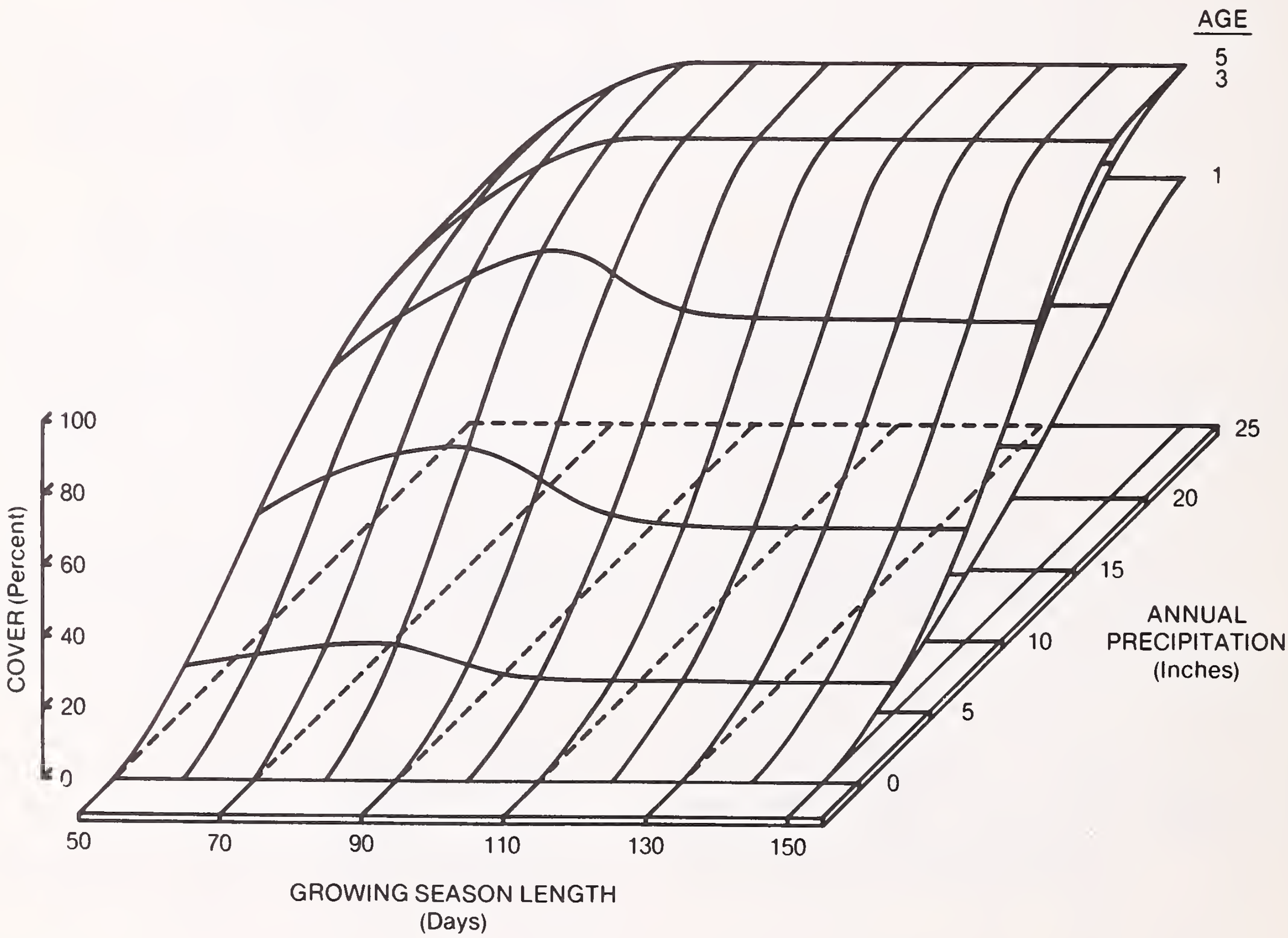

Figure 4.—Effects of annual precipitation, growing season length, and age of planting on vegetative cover density of mined and revegetated sites on coal surface mines.

Table 4.—Effects of climatic factors, spoil properties, and revegetation treatments on vegetative cover density of mined sites revegetated predominantly with native species (percent)

MINED AREAS
NATIVE SPECIES COVER

PR 5, GS 85, K 200, NA 300, PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	% COVER
							7
X							3
	X						5
		X					13
			X				18
				X			7
					X		22
						X	1
X	X						1
X		X					9
X			X				14
X				X			4
X					X		18
X						X	0
	X	X					11
	X		X				16
	X			X			6
	X				X		20
	X					X	0
		X	X				24
		X		X			13
		X			X		28
		X				X	7
			X	X			19
			X		X		33
			X			X	12
				X	X		23
				X		X	2
					X	X	16
X	X	X					7
X	X		X				12
X	X			X			2
X	X				X		16
X	X					X	0
X		X	X				20
X		X		X			10
X		X			X		24
X		X				X	3
X			X	X			15
X			X		X		29
X			X			X	9
X				X	X		19
X				X		X	0
X					X	X	12
	X	X	X				22
	X	X		X			12
	X	X			X		26
	X	X				X	5
	X		X	X			17

PR 15, GS 85, K 200, NA 300, PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	% COVER
							76
X							72
	X						75
		X					82
			X				88
				X			77
					X		92
						X	71
X	X						71
X		X					78
X			X				84
X				X			73
X					X		88
X						X	67
	X	X					81
	X		X				86
	X			X			75
	X				X		90
	X					X	69
		X	X				94
		X		X			83
		X			X		98
		X				X	77
			X	X			88
			X		X		100
			X			X	82
				X	X		92
				X		X	71
					X	X	86
X	X	X					77
X	X		X				82
X	X			X			71
X	X				X		86
X	X					X	65
X		X	X				90
X		X		X			79
X		X			X		94
X		X				X	73
X			X	X			84
X			X		X		99
X			X			X	78
X				X	X		88
X				X		X	67
X					X	X	82
	X	X	X				92
	X	X		X			81
	X	X			X		96
	X	X				X	75
	X		X	X			86

PR 25, GS 85, K 200, NA 300, PH 8

TIL	SM	TPS	FER	IRR	MUL	ST	% COVER
							94
X							90
	X						92
		X					100
			X				100
				X			95
					X		100
						X	89
X	X						88
X		X					96
X			X				100
X				X			91
X					X		100
X						X	85
	X	X					98
	X		X				100
	X			X			93
	X				X		100
	X					X	87
		X	X				100
		X		X			100
		X			X		100
		X				X	95
			X	X			100
			X		X		100
			X			X	100
				X	X		100
				X		X	89
					X	X	100
X	X	X					94
X	X		X				100
X	X			X			89
X	X				X		100
X	X					X	83
X		X	X				100
X		X		X			97
X		X			X		100
X		X				X	91
X			X	X			100
X			X		X		100
X			X			X	96
X				X	X		100
X				X		X	85
X					X	X	100
	X	X	X				100
	X	X		X			99
	X	X			X		100
	X	X				X	93
	X		X	X			100

APPLICATION

The outputs from this research include two regression models for **unmined** (undisturbed) areas, one for use in estimating forage production weights and the other for estimating vegetative cover densities. Also included are four regression models for **mined** areas. Two models are for use in estimating forage production weights, one where native plants predominate, the other where introduced plant species are dominant. The other two models are for use in estimating vegetative cover densities of native and of introduced vegetation.

Each of these six models is expressed as an algebraic equation in appendix A. Following each of these equations are FORTRAN IV computer programs to facilitate computer solutions for pertinent combinations of the different levels of the independent variables involved and, as appropriate, for native and introduced species. The values contained in tables 1, 2, 3, and 4 are sample outputs from these FORTRAN programs.

Another output from this research consists of two multicolored maps (scale 1:1,000,000) that depict the following information for the surface mineable coal areas of the West, as well as for most of the intervening areas (appendix B, inside back cover).

1. Annual precipitation (inches);
2. Growing season length (days);
3. Natural vegetation types and their identification numbers (Küchler 1964);
4. Soil associations and their identification numbers (Aandahl 1972; Cipra and others 1977; Jay and others 1975; Maker and others 1974; Southard 1973; Wilson and others 1975; and Young and Singleton 1977).

These maps provide estimates of precipitation and growing season length and identify the soil association and natural vegetation type for any location on surface-mineable coal areas of the West.

Here are instructions covering use of the maps, equations, and tables in order to estimate the average degree of revegetation success on any of these surface-mineable coal areas.

1. For any selected location on either of the maps determine values of precipitation and growing season length and identify the soil association and vegetation type by numbers. The soil association numbers are those contained either in Soils of the Great Plains (Aandahl 1972) or in individual State soil description publications (Cipra and others 1977; Jay and others 1975; Maker and others 1974; Southard 1973; Wilson and others 1975; and Young and Singleton 1977), which are referenced in the Publications Cited section. These publications contain information concerning the chemical and physical characteristics of the soil associations. The vegetation type numbers are contained in Küchler's 1964 map of "The Potential Natural Vegetation of the Conterminous United States." This map identifies the dominant native species that make up each vegetation type. Such identification provides ecological guides to selection of plant species adapted for revegetation purposes.

2. Use the values of annual precipitation, growing season length, and soil potassium content in equation 1, appendix A for unmined areas to calculate forage production in pounds per acre. Similarly, the values of these factors can be used in equation 2, appendix A to calculate cover density in percent. These values are considered to define the ecological potential for producing forage and developing cover density at this location. If published information concerning the chemical characteristics of the particular soil association under consideration is not available, then soil sampling may be necessary to obtain site specific data on the soil potassium content.

3. Depending upon whether revegetation of **mined areas** or planned revegetation of **areas to be mined** is with native or with introduced types of vegetation, enter the appropriate version of the **mined areas** interactive component equation (equation 3, appendix A) with the same precipitation and growing season values that were used in the unmined area equations. Calculate the interactive effects of these factors on the estimated pounds per acre of forage produced at age 5 years.

4. Enter the appropriate additive component table for forage production (table 1, appendix A). Calculate additional effects on forage production of spoil potassium, sodium, and pH conditions encountered or expected, as well as additional effects of the seven revegetation treatments indicated. In the event that previous mine spoil analyses are not available or do not provide sufficient information on potassium, sodium, and pH levels, spoil sampling may be necessary to obtain specific on-site values of these factors.

5. Add the pounds per acre of forage production calculated from the interactive component equation to the pounds per acre calculated from the additive component table. These values are the estimated forage production amounts achievable under the climatic, spoil, and revegetation treatment conditions encountered.

6. Similar calculations of achievable plant cover densities can be made utilizing the climatic, spoil, and revegetation treatment factors in the interactive component equation (equation 4, appendix A) and additive component table (table 2, appendix A) for plant cover density.

7. Select those alternative revegetation treatment combinations that provide forage production weight and plant cover density values equal to or greater than the values from the comparable unmined area equations. These values denote success compared to the ecological standards for existing conditions and they identify the combinations of climatic, spoil, and revegetation treatment conditions needed to achieve such success 5 years after planting.

Following is an example of the use of the maps, tables, and equations to compare estimated forage production weights of predominantly native vegetation on a selected unmined and mined site in eastern Montana.

1. From the maps, it is determined that the average annual precipitation at the selected site is 15 inches (38 cm). The growing season length is 85 days. The soil association is Aandahl's number 117, which is moderately low in potassium (less than 200 p/m), high in sodium (more than 300 meq/L), and high in pH (about 8). The vegetation type is Küchler's number 6, grassland-sagebrush, which contains a number of highly adapted and suitable grass and shrub species for revegetation.

2. Utilizing this information, enter table 1 in the center section: 200 p/m of potassium, 15 inches (38 cm) of precipitation, and 85 days of growing season. This combination of conditions results in a tabulated estimate of 1,531 pounds per acre (1 716 kg/ha) of native vegetation weight produced on the unmined site, the ecological potential for this site. This same value, 1,531 pounds per acre can be obtained by solving equation 1, appendix A as follows:

$$\begin{aligned} N &= 1.8 - 0.56 * e^{-0.01770} \\ &= 1.8 - 0.56 * 0.9825 = 1.250 \end{aligned}$$

$$\begin{aligned} YPFL &= 1{,}570 + 1{,}060 * e^{-0.00056} \\ &= 1{,}570 + 1{,}060 * 0.9994 = 2{,}629.4 \end{aligned}$$

$$\begin{aligned} YP1 &= YPFL + 560 * e^{-0.25025} \\ &= 2{,}629.4 + 560 * 0.7786 = 3{,}065.4 \end{aligned}$$

$$\begin{aligned} PRODUCTION &= \frac{3{,}065.4}{(25)^{1.25}} * (15)^{1.25} * 0.94584 \\ &= 1{,}531 \text{ pounds/acre} \end{aligned}$$

3. Further utilizing the information obtained from the maps and the cited soil reference (Aandahl 1972), enter table 3 in the center section. Here, the native vegetation production weight estimates are for 15 inches (38 cm) of precipitation, 85 days of growing season, 200 p/m of potassium, 300 meq/liter of sodium, and pH of 8—the conditions encountered at this site. This combination of conditions, together with the various revegetation treatment combinations indicated in the table, results in a number of production weight estimates in excess of 1,531 pounds per acre (1 716 kg/ha) when the vegetation on the mined areas is 5 years old. The highest production weight in that portion of the total table represented by table 3—2,214 lb/acre (2 482 kg/ha)—can be achieved by selecting a combination of treatments that includes drilling seed in the spring, fertilizing the area with a well-balanced N—P—K fertilizer, and irrigating. Very nearly the same production level (2,186 lb/acre or 2 450 kg/ha) can be achieved by tilling, drilling in the fall, and fertilizing without irrigation. Almost as much production (2,173 lb/acre or 2 436 kg/ha) is obtainable with much less effort and expense simply by drilling and fertilizing in the fall without either tillage or irrigation.

These estimates of forage production weight can be obtained by solving equation 3, appendix A and adding the appropriate elements from the additive component table (table 1, appendix A). This solution for the maximum weight of 2,214 lb/acre (2 482 kg/ha) is as follows:

a. **Equation 3**

$$\begin{aligned} PRODUCTION &= 0.0061896 * YPPR * YPGS \\ &\quad * (PR)^{1.6} * 1.04368 \end{aligned}$$

$$YPPR = e^{-0.00510} = 0.99491$$

$$\begin{aligned} YPGS &= 940 + 2{,}510 * e^{-0} \\ &= 940 + 2{,}510 * 1 = 3{,}450 \end{aligned}$$

$$\begin{aligned} PRODUCTION &= 0.0061896 * 0.99491 * 3{,}450 \\ &\quad * (15)^{1.6} * 1.04368 \\ &= 1{,}688 \text{ pounds/acre} \end{aligned}$$

b. **Additive components (native vegetation)**

Soil potassium (K)	200 * 5.4	=	1,080
Soil sodium (Na)	300 * (−0.088)	=	−26
Soil acidity (pH)	8 * 117.9	=	944
Intercept			−2,216
Seed drilled			341
Fertilizer			369
Irrigation			35
Spring seeding			0
Additive components total			526 pounds/acre
Total production (1,688 + 526)			2,214 pounds/acre

c. These forage production weight values—up to 2,214 pounds per acre (2 482 kg/ha) on revegetated mined areas compared to only 1,531 pounds per acre (1 716 kg/ha) on similar but unmined sites—indicate that successful revegetation can be achieved on mined sites characterized by the climatic, soil, and treatment conditions specified in this example. Still unanswered are questions concerning the permanency of production weights of such magnitude in the absence of further fertilization or of what the land management requirements are to maintain such production. Examination of the complete computer-produced tables leads one to conclude, however, that revegetation treatment alternatives are available to produce forage weights (and cover densities) which, 5 years after establishment, are greater than the ecological potentials of most western coal mine sites.

4. The algebraic specifications for the six models are presented in appendix A as equations. Immediately following each is an associated FORTRAN IV computer program designed to produce tables like the text examples (tables 1-4). Note that these programs are designed to run on IBM or IBM-compatible systems such as the Amdahl 470V/6-II. Minor program changes, such as "read" and "write" instructions and a substitute for the standard IBM ERRSET subroutine, may have to be made before they will run on alternative systems.

In the programs for mined areas, three groups of preselected values of PR, GS, K, Na, and pH (in this sequence) are used in statement 003 as a major control for program output. The values are: 5, 50, 0, 0, 4; 15, 85, 200, 150, 6; and 25, 120, 400, 300, 8. These can be changed to accommodate alternative output needs, but must be within the limits of use specified for each variable and algebraic model. The output format for vegetative treatments is considered fixed and should not be altered.

The program for unmined areas produces both forage production and cover percent estimates. Only three variables control the output here, PR, GS, and K. Three preselected values of each appear in the program as follows:

Statement 0008, where K = 50, 120, 35. K represents GS here and the statement is interpreted to mean that

GS levels start at 50, and are incremented by 35 until the maximum of 120 is reached. Thus, GS—levels = 50, 85, and 120.

Statement 0010, where LL = 1, 401, 200. LL represents K and the statement is interpreted as in 0008, so that K levels are 1, 201, and 401. "One" has been added to the desired values of 0, 200, and 400 to accommodate a programming limitation at zero. One is subtracted (in statement 0011) before model computations are begun so that the final output is for K levels of 0, 200, and 400.

Statement 0012, where M = 5, 25, 10. M represents PR and the statement is interpreted as in 0008, so that the PR levels are 5, 15, and 25.

The levels of these variables can be changed to meet alternative output needs but, again, must be within the limits specified for each variable and algebraic model.

Neither pagination nor indexing is provided in these programs. It is suggested that users add such provisions for convenience in application of the many tables generated (243 tables here).

DISCUSSION

The primary objectives of this investigation were to develop capabilities for estimating the degree of revegetation success to be expected under a wide variety of climatic conditions, soil and spoil properties, and revegetation treatments utilizing site-specific revegetation data and information from most of the coal surface mines in the interior West. The more important study developments are these:

- A strong conceptual framework for evaluating the success of proposed vegetative rehabilitation efforts on areas to be surface mined.
- Site-specific maps have been developed to provide precipitation, growing season length, soil, and vegetation type information, critical to the evaluation system.
- Results of most existing surface-mine rehabilitation efforts in the interior West through 1976 were surveyed as a basis for evaluating revegetation success.
- Interim predictors (models) were developed, based on these survey data, for forage production and cover density potentials on:
  - Undisturbed sites adjacent to the study mines.
  - Mined areas with various combinations of planting and postplanting methods and treatments designed to enhance the total rehabilitation effort for:
    - Native species;
    - Introduced species.

This investigation shows that practical criteria for measuring revegetation success, namely, the amount of forage produced and the density of plant cover developed, are affected significantly by at least two major climatic factors that are not readily susceptible to alteration (PR and GS); by three properties of spoil materials that are subject to limited modification through management (K, Na, and pH). Revegetation success is also influenced by seven revegetation treatments, each of which provides at least two management alternatives, and by the age of the vegetation. These characteristics account for about one-half to three-fourths of the total variance in forage production and plant cover density in the prediction models (table 3, appendix A).

It is emphasized here that the models should be used with considerable discretion since the source data, while the best available, is weak in many respects. First, there were only 34 mines in the entire area covered by this study where revegetation was even attempted. The kinds of revegetation efforts, insofar as specific treatments or combinations of treatments are concerned, differ between mines and, in many cases, even between years on the same mine. For example, seeds of native species may be broadcast in the fall on the spoils of one mine, whereas seeds of introduced species may be drilled into the soils of another mine in the spring. In each case, the combinations of other treatments, such as topsoiling, tilling, mulching, or fertilizing, might be substantially different. Of the large number of possible treatment combinations, relatively few exist on the 28 mines studied, and the comparative revegetation success of those that do exist is confounded by mine-to-mine differences in climatic and growing media environment. Further, "treatments" cannot be considered to be standardized. For example, the depth and quality of topsoil (when added) are almost certain to differ between mines. Fertilizer composition and rates and times of application are largely unknown. Also unknown are rates of seed application, depths of drilled seed, the quality of seed, the mix of species seeded, the depth of tillage, the kinds and amounts of mulch applied, and supplemental irrigation amounts and frequencies. At the time of this study, about half of the revegetation efforts were no more than 2 years old; so, on the mines involved, seeded plants had not had time to respond fully to the growing environment and revegetation treatments. Revegetation success, of course, is strongly affected by the particular amount and timing of precipitation during the year or period of years involved in the revegetation effort.

It seems certain that the interest in western coal development and associated environmental controls will continue for a number of years. Under these circumstances and because of the low-order quantitative information available on the success of spoil rehabilitation efforts, we recommend *strongly* that extensive, well-planned experimentation be underwritten by the agencies requiring this information. Although such research is now underway in the Forest Service, it is of limited scope and cannot fully meet all of the management needs specified.

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APPENDIX A CONTENTS

APPENDIX A — EQUATIONS AND SUPPLEMENTAL TABLES FOR USE IN ESTIMATING FORAGE PRODUCTION WEIGHTS AND PLANT COVER DENSITIES

The figures and partial tables presented in this paper are useful as an aid in understanding the relations described by the models for estimating forage production weights and plant cover densities. They are not particularly effective, however, as tools for generating such estimates. Needed to estimate useful values of forage production and plant cover density are the equations for the interactive portions of these models (both unmined and mined area models) and the tables for the additive components (mined-area models only). These equations and additive-effect tables follow. Note that the sum of the interactive fixed base and linear residual effects constitutes the estimate of total forage production weight or vegetation cover density. While these models can be solved readily with most pocket calculators, computerized solutions are strongly recommended if production of tables of estimates is the desired end product.

1. Equations for unmined areas
   The models for unmined areas are basically interactive.
   a. Forage production model equation (Equation 1)

$$\widehat{\text{Production}} = \left\{ \frac{YPi}{(25)^N} (PR)^N \right\} * 0.94584$$

$$N = 1.8 - 0.56 * e^{-\left| \frac{\frac{(180\ -\ GS)}{106} - 1}{0.3} \right|^{3.8}}$$

If GS ≤ 87

$$YP1 = YPFL + 560 * e^{-\left| \frac{\frac{K}{450} - 1}{0.6} \right|^{18}}$$

$$YPFL = 1570 + 1060 * e^{-\left| \frac{\frac{GS}{86.6} - 1}{0.12} \right|^{4}}$$

If GS > 87

$$YP2 = 1700 + (YP1^{1/} - 1700) * e^{-\left| \frac{\frac{(180-GS)}{93.4} - 1}{0.09} \right|^{3}}$$

LIMITS

5 ≤ PR ≤ 25	PR = annual precipitation, inches
50 ≤ GS ≤ 180	GS = growing season, days
0 ≤ K ≤ 450	K = potassium, p/m

[1] @ YPFL = 2630

b. Plant cover density model equation (Equation 2)

$$\widehat{\text{Cover}} = YP * \left[\frac{e^{-\left|\frac{\frac{PR}{25} - 1}{(1-I)}\right|^{5}} - e^{-\left\{\frac{1}{(1-I)}\right\}^{5}}}{1 - e^{-\left\{\frac{1}{(1-I)}\right\}^{5}}} \right] * 0.97917$$

$$YP = YPFL + YPAD$$

$$YPFL = 80 + 20 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.46}\right|^{15}}$$

$$YPAD = \left[9 * e^{-\left|\frac{\frac{K}{400} - 1}{0.43}\right|^{15}} \right] * \left[1 - e^{-\left|\frac{\frac{GS}{180} - 1}{0.46}\right|^{15}} \right]$$

$$I = 0.14 + 0.285 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.46}\right|^{15}}$$

LIMITS

$5 \leq PR \leq 25$	PR = annual precipitation, inches
$50 \leq GS \leq 180$	GS = growing season, days
$0 \leq K \leq 450$	K = potassium, p/m

c. FORTRAN IV computer programs for estimating forage production (equation 1) and plant cover density (equation 2)

```
      REAL I,LN
      DIMENSION CLP(9)
      CALL ERRSET (208,256,-1,0)
      PRINT 101
      DO 30 J=1,2
      IF(J.EQ.2) PRINT 100
      PRINT 102
      DO 25 K=50,120,35
      N=0
      DO 20 LL=1,401,200
      L=LL-1
      DO 18 M=5,25,10
      GS=K
      PR=M
      PO=L
      N=N+1
      IF(J.EQ.2) GO TO 26
      I=.14+.285*(EXP(-(ABS((GS/180.-1.)/.46)**15)))
      YPFL=80.+20.*(EXP(-(ABS((GS/180.-1.)/.46)**15)))
      YPA=1.-(EXP(-(ABS((GS/180.-1.)/.46)**15)))
      YPD=9.*(EXP(-(ABS((PO/400.-1.)/.43)**15)))
      YP=YPFL+YPA*YPD
      LN=EXP(-(ABS((PR/25.-1.)/(1.-I))**5))
      RN=EXP(-((1./(1.-I))**5))
      CLP(N)=((LN-RN)/(1.-RN))*YP*.97917
   18 CONTINUE
   20 CONTINUE
      PRINT 103,K,(CLP(II),II=1,3),K,(CLP(II),II=4,6),K,(CLP(II),II=7,9)
   25 CONTINUE
      PRINT 104
      GO TO 30
   26 YN=1.8-.56*(EXP(-(ABS(((180.-GS)/106.-1.)/.3)**3.8)))
      YPFL=1570.+1060.*(EXP(-(ABS((GS/86.6-1.)/.12)**4)))
      YP1=YPFL+560.*(EXP(-(ABS((PO/450.-1.)/.6)**18)))
      IF(GS.GT.86.6) GO TO 28
   27 CLP(N)=((YP1/25.**YN)*PR**YN)*.94584
      GO TO 18
   28 YP1=1700.+(YP1-1700.)*(EXP(-(ABS(((180.-GS)/93.4-1.)/.09)**3)))
      GO TO 27
   30 CONTINUE
      STOP
  100 FORMAT('1',39X,'U N M I N E D   A R E A S'/' ',47X,
     *'F O R A G E'/' ',28X,'P R O D U C T I O N   P O U N D S',
     *'   P E R   A C R E')
  101 FORMAT('-',39X,'U N M I N E D   A R E A S'/' ',47X,
     *'F O R A G E'/' ',34X,'P E R C E N T A G E   O F   C O V E R')
  102 FORMAT('0',7X,'NO POTASSIUM',20X,'200 PARTS/MILLION POTASSIUM',
     *12X,'400 PARTS/MILLION POTASSIUM'/' ',
     *3('+',7('='),'+',17('-'),'+',12X)/' ',
     *3(':DAYS OF:     INCHES       :',12X)/' ',
     *3(':GROWING:  PRECIPITATION  :',12X)/' ',
     *3(': SEASON:  5      15    25 :',12X)/' ',
     *3('+',7('-'),'+',17('-'),'+',12X))
  103 FORMAT('0',3(':  ',I3,'  :',2(F5.0,1X),F5.0,':',12X))
  104 FORMAT('0',3('+',7('-'),'+',17('-'),'+',12X))
      END
```

2. Equations for mined areas
   The models for mined areas are partially interactive and partially additive.
   a. Forage production model
      (1) Interactive component equation (Equation 3)

$$\widehat{\text{Production}} = 0.0061896 * \text{YPPR} * \text{YPGS} * (\text{PR})^{1.6} * \begin{array}{l}\underline{\text{Kind of vegetation}}\\ 1.04368 \text{ (native)} \\ 1.17448 \text{ (introduced)}\end{array}$$

$$\text{YPPR} = e^{-\left|\frac{\frac{\text{AGE}}{7} - 1}{0.9}\right|^{4.6}}$$

<u>If GS ≤ 85</u>

$$\text{YPGS} = 940 + 2510 * e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.16}\right|^{4}}$$

<u>If GS > 85</u>

$$\text{YPGS} = 2250 + 1200 * e^{-\left|\frac{\frac{\text{GS}}{85} - 1}{0.12}\right|^{4}}$$

<u>LIMITS</u>

$5 \leq \text{PR} \leq 25$	PR = annual precipitation, inches
$50 \leq \text{GS} \leq 180$	GS = growing season, days
$0 \leq \text{AGE} \leq 7$	AGE = age of planting, years

(2) Additive component table (Table 1)

Component	Additive forage production (lbs/acre) Native	Introduced
Soil potassium (K)	[1]+ 5.4	[1]+ 4.1
Soil sodium (Na)	[1]– 0.088	[1]– 1.4
Soil pH	[2]+ 117.9	[2]+ 143.4
Tillage (Til)	+ 13.0	– 308.0
Seeding method (SM)		
broadcast	0	0
drilled	+ 341.0	– 783.0
Topsoil (TPS)	– 83.0	+ 99.0
Fertilizer (FER)	+ 369.0	+ 430.0
Irrigation (IRR)	+ 35.0	+ 418.0
Mulching (MUL)	– 178.0	+ 160.0
Seeding time (ST)		
spring	0	0
fall	+ 335.0	– 78.0
Intercept	[3]– 2216.0	[3]– 1181.0

[1]Multiply these production values by parts per million of soil component (potassium or sodium).
[2]Multiply these production values by pH units of soil acidity.
[3]These intercept values **must** be added to the total value of forage production.

<u>LIMITS</u>

$0 \leq \text{K} \leq 450$
$0 \leq \text{Na} \leq 1000$
$4 \leq \text{pH} \leq 9$

(3) FORTRAN IV computer programs for estimating forage production (equation 3) for:

(a) Native vegetation

```
      DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
      INTEGER*2 N(7)
      DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
     *N/7*0/,X/'X'/,A/7*' '/,B/' '/
      CALL ERRSET (208,256,-1,0)
      DO 45 MM=1,3
      DO 45 M=1,3
      DO 45 L=1,3
      DO 45 K=1,3
      DO 20 I=1,3
      Z=IX(2,K)
      YPPR=(EXP(-(ABS((5.0/7.0-1.0)/.9)**4.6)))
      IF(IX(2,K).GT.85) GO TO 10
      YPG1=2510*(EXP(-(ABS((Z/85.-1.)/.16)**4)))+940
      XT(I)=YPPR*YPG1*.00618959*FLOAT(IX(1,I))**1.6
      GO TO 15
   10 YPG2=1200*(EXP(-(ABS((Z/85.-1.)/.12)**4)))+2250
      XT(I)=YPPR*YPG2*.00618959*FLOAT(IX(1,I))**1.6
   15 XT(I)=XT(I)*1.04368
C *** FOR ZERO COMPUTATION. ***
      LB(I)=-2215.925+XT(I)+IX(3,L)*5.39904+IX(4,M)*(-.08788242)+
     *IX(5,MM)*117.9473
      IF(LB(I).LT.0) LB(I)=0
   20 CONTINUE
      PRINT 99
      PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
      PRINT 101,(LB(I),I=1,3)
      DO 40 I=1,127
      READ(9,102,END=50) N
      DO 25 J=1,3
      LB(J)=-2215.925+XT(J)+IX(3,L)*5.39904+IX(4,M)*(-.08788242)+
     *IX(5,MM)*117.9473+N(1)*13.30125+N(2)*340.7638+N(3)*(-83.07744)+
     *N(4)*368.7023+N(5)*34.89601+N(6)*(-177.5357)+N(7)*334.5793
      IF(LB(J).LT.0) LB(J)=0
   25 CONTINUE
      DO 30 J=1,7
      IF(N(J).EQ.1) A(J)=X
   30 CONTINUE
      PRINT 103,(A,LB(J),J=1,3)
      DO 35 J=1,7
      IF(A(J).EQ.X) A(J)=B
   35 CONTINUE
   40 CONTINUE
      REWIND 9
   45 CONTINUE
   50 STOP
   99 FORMAT('1',52X,'M I N E D   A R E A S'/' ',41X,
     *'N A T I V E   S P E C I E S   P R O D U C T I O N')
  100 FORMAT('0',3(35('-'),9X)/' ',3(': PR   GS   K',
     *'    NA   PH    :      :',9X)/' ',3(': ',I2,2X,4(I3,2X),
     *2X,':      :',9X)/' ',3(':',27X,': PROD:',9X)/' ',
     *3(':',7('---+'),'  PER:',9X)/' ',3(':TIL  SM TPS ',
     *'FER IRR MUL  ST: ACRE:',9X)/' ',3(8('+---'),'--+',
     *9X))
  101 FORMAT(' ',3(':',27X,I6,':',9X))
  102 FORMAT(7I1)
  103 FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
      END
```

(b) Introduced vegetation

```
      DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
      INTEGER*2 N(7)
      DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
     *N/7*0/,X/'X'/,A/7*' '/,B/' '/
      CALL ERRSET (208,256,-1,0)
      DO 45 MM=1,3
      DO 45 M=1,3
      DO 45 L=1,3
      DO 45 K=1,3
      DO 20 I=1,3
      Z=IX(2,K)
      YPPR=(EXP(-(ABS((5.0/7.0-1.0)/.9)**4.6)))
      IF(IX(2,K).GT.85) GO TO 10
      YPG1=2510*(EXP(-(ABS((Z/85.-1.)/.16)**4)))+940
      XT(I)=YPPR*YPG1*.00618959*FLOAT(IX(1,I))**1.6
      GO TO 15
   10 YPG2=1200*(EXP(-(ABS((Z/85.-1.)/.12)**4)))+2250
      XT(I)=YPPR*YPG2*.00618959*FLOAT(IX(1,I))**1.6
   15 XT(I)=XT(I)*1.17448
C *** FOR ZERO COMPUTATION. ***
      LB(I)=-1180.820+XT(I)+IX(3,L)*4.08251+IX(4,M)*(-1.361515)+
     *IX(5,MM)*143.3554
      IF(LB(I).LT.0) LB(I)=0
   20 CONTINUE
      PRINT 99
      PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
      PRINT 101,(LB(I),I=1,3)
      DO 40 I=1,127
      READ(9,102,END=50) N
      DO 25 J=1,3
      LB(J)=-1180.820+XT(J)+IX(3,L)*4.08251+IX(4,M)*(-1.361515)+
     *IX(5,MM)*143.3554+N(1)*(-307.9574)+N(2)*(-782.8676)+N(3)*99.46091+
     *N(4)*429.5873+N(5)*418.1331+N(6)*159.9511+N(7)*(-78.4929)
      IF(LB(J).LT.0) LB(J)=0
   25 CONTINUE
      DO 30 J=1,7
      IF(N(J).EQ.1) A(J)=X
   30 CONTINUE
      PRINT 103,(A,LB(J),J=1,3)
      DO 35 J=1,7
      IF(A(J).EQ.X) A(J)=B
   35 CONTINUE
   40 CONTINUE
      REWIND 9
   45 CONTINUE
   50 STOP
C     DEBUG INIT(LB,XT),UNIT(2)
   99 FORMAT('1',52X,'M I N E D   A R E A S'/' ',33X,
     *'I N T R O D U C E D   S P E C I E S   P R O D U C T I O N')
  100 FORMAT('0',3(35('-'),9X)/' ',3(': PR   GS   K',
     *'    NA   PH    :      :',9X)/' ',3(':  ',I2,2X,4(I3,2X),
     *2X,':      :',9X)/' ',3(':',27X,': PROD:',9X)/' ',
     *3(':',7('---+'),'  PER:',9X)/' ',3(':TIL  SM TPS ',
     *'FER IRR MUL  ST: ACRE:',9X)/' ',3(8('+---'),'--+',
     *9X))
  101 FORMAT(' ',3(':',27X,I6,':',9X))
  102 FORMAT(7I1)
  103 FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
      END
```

b. Plant cover density model

(1) Interactive component equation (Equation 4)

$$\text{Cover} = YP * \left[\frac{e^{-\left|\frac{\frac{PR}{26} - 1}{1 - I}\right|^{N}} - e^{-\left\{\frac{1}{1 - I}\right\}^{N}}}{1 - e^{-\left\{\frac{1}{1 - I}\right\}^{N}}} \right] * \begin{array}{ll} & \text{Kind of } \underline{\text{vegetation}} \\ 1.07686 & \text{(Native)} \\ 0.98256 & \text{(introduced)} \end{array}$$

Where

$$N = 1 + NYP * \left(1.1397 * e^{-\left|\frac{\frac{AGE}{10} - 1}{0.88}\right|^{5.8}} - 0.1397\right)$$

$$NYP = 1.8 + e^{-\left|\frac{\frac{(180 - GS)}{108} - 1}{0.52}\right|^{15}}$$

$$I = 0.38 + (IYP/10) * AGE$$

$$IYP = 0.29 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.5105}\right|^{12}} - 0.2$$

$$YP = YPGS * \left[\frac{e^{-\left|\frac{\frac{(AGE + 1)}{11} - 1}{(1 - IGS)}\right|^{10}} - e^{-\left\{\frac{1}{(1 - IGS)}\right\}^{10}}}{1 - e^{-\left\{\frac{1}{(1 - IGS)}\right\}^{10}}} \right]$$

$$YPGS = 100 * e^{-\left|\frac{\frac{GS}{180} - 1}{0.78}\right|^{8}}$$

$$IGS = 0.1 + 0.23 * e^{-\left|\frac{\frac{(180 - GS)}{180} - 1}{0.36}\right|^{6.5}}$$

LIMITS

$5 \leq PR \leq 25$	PR = annual precipitation, inches
$50 \leq GS \leq 180$	GS = growing season, days
$0 \leq AGE \leq 7$	AGE = age of planting, years

(2) Additive component table (Table 2)

Component	Additive plant cover density (percent)	
	Native	Introduced
Soil potassium (K)	[1]0.0892	[1]0.0205
Soil sodium (Na)	[1] − 0.0186	[1]0.0093
Soil pH	[2] − 4.2	[2] + 7.6
Tilliage (Til)	− 3.9	− 10.0
Seeding method (SM)		
broadcast	0	0
drilled	− 1.8	+ 1.0
Topsoil (TPS)	+ 6.0	+ 0.4
Fertilizer (FER)	+ 11.2	+ 30.9
Irrigation (IRR)	+ 0.6	+ 15.0
Mulching (MUL)	+ 15.2	+ 4.8
Seeding time (ST)		
spring	0	0
fall	− 5.6	+ 19.0
Intercept	[3] + 12.9	[3] − 74.3

[1]Multiply these density (percent) values by parts per million of soil component (potassium or sodium).
[2]Multiply these density values by pH units of soil acidity.
[3]These intercept values **must** be added to the total value of cover density.

LIMITS

$0 \leq K \leq 450$
$0 \leq Na \leq 1000$
$4 \leq pH \leq 9$

(3) FORTRAN IV computer programs for estimating plant cover density (equation 4) for:
(a) Native vegetation

```
            DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
            INTEGER*2 N(7)
            DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
           *N/7*0/,X/'X'/,A/7*' '/,B/' '/
            CALL ERRSET (208,256,-1,0)
            DO 45 MM=1,3
            DO 45 M=1,3
            DO 45 L=1,3
            DO 45 K=1,3
            DO 20 I=1,3
            V=IX(1,I)
            Z=IX(2,K)
            AYP=1.8+EXP(-(ABS(((180-Z)/180.-1.)/.52)**15))
            BYP=.29*(EXP(-(ABS((Z/180.-1.)/.5105)**12)))-.2
            YPGS=100.*(EXP(-(ABS((Z/180.-1.)/.78)**8)))
            BGS=.23*(EXP(-(ABS(((180.-Z)/180.-1.)/.36)**6.5)))+.1
            AX=AYP*(1.1397*(EXP(-(ABS((5./10.-1.)/.88)**5.8)))-.1397)+1
            BX=(BYP/10.)*5.+.38
            CN=EXP(-(ABS(((5.+1)/11.-1.)/(1.-BGS))**10))
            RN=EXP(-((1./(1.-BGS))**10))
            YP=((CN-RN)/(1.-RN))*YPGS
            TN=EXP(-(ABS((V/26.-1.)/(1.-BX))**AX))
            UN=EXP(-((1./(1.-BX))**AX))
            COV=((TN-UN)/(1.-UN))*YP
            XT(I)=COV*1.07686
C *** FOR ZERO COMPUTATION. ***
            LB(I)=12.86572+XT(I)+IX(3,L)*.08918672+IX(4,M)*(-.01861335)+
           *IX(5,MM)*(-4.176856)
            IF(LB(I).LT.0) LB(I)=0
            IF(LB(I).GT.100) LB(I)=100
   20       CONTINUE
            PRINT 99
            PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
            PRINT 101,(LB(I),I=1,3)
            DO 40 I=1,127
            READ(9,102,END=50) N
            DO 25 J=1,3
            LB(J)=12.86572+XT(J)+IX(3,L)*.08918672+IX(4,M)*(-.01861335)+
           *IX(5,MM)*(-4.176856)+N(1)*(-3.929149)+N(2)*(-1.836147)+N(3)*
           *6.056078+N(4)*11.19705+N(5)*.5945488+N(6)*15.16765+N(7)*
           *(-5.601713)
            IF(LB(J).LT.0) LB(J)=0
            IF(LB(J).GT.100) LB(J)=100
   25       CONTINUE
            DO 30 J=1,7
            IF(N(J).EQ.1) A(J)=X
   30       CONTINUE
            PRINT 103,(A,LB(J),J=1,3)
            DO 35 J=1,7
            IF(A(J).EQ.X) A(J)=B
   35       CONTINUE
   40       CONTINUE
            REWIND 9
   45       CONTINUE
   50       STOP
C           DEBUG INIT(LB,XT),UNIT(2)
   99       FORMAT('1',52X,'M I N E D   A R E A S'/' ',41X,
           *'N A T I V E   S P E C I E S   C O V E R')

  100       FORMAT('0',3(35('-'),9X)/' ',3(': PR   GS   K',
           *'    NA   PH    :       :',9X)/' ',3(': ',I2,2X,4(I3,2X),
           *2X,':       :',9X)/' ',3(':',27X,':       :',9X)/' ',
           *3(':',7('---+'),'   %  :',9X)/' ',3(':TIL  SM TPS ',
           *'FER IRR MUL  ST:COVER:',9X)/' ',3(8('+---'),'--+',
           *9X))
  101       FORMAT(' ',3(':',27X,I6,':',9X))
  102       FORMAT(7I1)
  103       FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
            END
```

(b) Introduced vegetation

```
          DIMENSION IX(5,3),LB(3),A(7) ,XT(3)
          INTEGER*2 N(7)
          DATA IX/5,50,0,0,4,15,85,200,150,6,25,120,400,300,8/,
         *N/7*0/,X/'X'/,A/7*' '/,B/' '/
          CALL ERRSET (208,256,-1,0)
          DO 45 MM=1,3
          DO 45 M=1,3
          DO 45 L=1,3
          DO 45 K=1,3
          DO 20 I=1,3
          V=IX(1,I)
          Z=IX(2,K)
          AYP=1.8+EXP(-(ABS((((180-Z)/180.-1.)/.52)**15))
          BYP=.29*(EXP(-(ABS((Z/180.-1.)/.5105)**12)))-.2
          YPGS=100.*(EXP(-(ABS((Z/180.-1.)/.78)**8)))
          BGS=.23*(EXP(-(ABS(((180.-Z)/180.-1.)/.36)**6.5)))+.1
          AX=AYP*(1.1397*(EXP(-(ABS((5./10.-1.)/.88)**5.8)))-.1397)+1
          BX=(BYP/10.)*5.+.38
          CN=EXP(-(ABS(((5.+1)/11.-1.)/(1.-BGS))**10))
          RN=EXP(-((1./(1.-BGS))**10))
          YP=((CN-RN)/(1.-RN))*YPGS
          TN=EXP(-(ABS((V/26.-1.)/(1.-BX))**AX))
          UN=EXP(-((1./(1.-BX))**AX))
          COV=((TN-UN)/(1.-UN))*YP
          XT(I)=COV*.98256
C *** FOR ZERO COMPUTATION. ***
          LB(I)=-74.25282+XT(I)+IX(3,L)*.02049003+IX(4,M)*.009275586+
         *IX(5,MM)*7.643977
          IF(LB(I).LT.0) LB(I)=0
          IF(LB(I).GT.100) LB(I)=100
   20     CONTINUE
          PRINT 99
          PRINT 100,(IX(1,I),IX(2,K),IX(3,L),IX(4,M),IX(5,MM),I=1,3)
          PRINT 101,(LB(I),I=1,3)
          DO 40 I=1,127
          READ(9,102,END=50) N
          DO 25 J=1,3
          LB(J)=-74.25282+XT(J)+IX(3,L)*.02049003+IX(4,M)*.009275586+
         *IX(5,MM)*7.643977+N(1)*(-10.02594)+N(2)*1.02198+N(3)*
         *.3622047+N(4)*30.88224+N(5)*15.06255+N(6)*4.778853+N(7)*18.96781
          IF(LB(J).LT.0) LB(J)=0
          IF(LB(J).GT.100) LB(J)=100
   25     CONTINUE
          DO 30 J=1,7
          IF(N(J).EQ.1) A(J)=X
   30     CONTINUE
          PRINT 103,(A,LB(J),J=1,3)
          DO 35 J=1,7
          IF(A(J).EQ.X) A(J)=B
   35     CONTINUE
   40     CONTINUE
          REWIND 9
   45     CONTINUE
   50     STOP
   99     FORMAT('1',52X,'M I N E D   A R E A S'/' ',33X,
         *'I N T R O D U C E D   S P E C I E S   C O V E R')
  100     FORMAT('0',3(35('-'),9X)/' ',3(': PR    GS    K',
         *'    NA    PH    :        :',9X)/' ',3(': ',I2,2X,4(I3,2X),
         *2X,':        :',9X)/' ',3(':',27X,':        :',9X)/' ',
         *3(':',7('---+'),'  %  :',9X)/' ',3(':TIL  SM TPS ',
         *'FER IRR MUL  ST:COVER:',9X)/' ',3(8('+---'),'--+',
         *9X))
  101     FORMAT(' ',3(':',27X,I6,':',9X))
  102     FORMAT(7I1)
  103     FORMAT(' ',3(':',1X,A1,6(3X,A1),1X,I6,':',9X))
          END
```

3. Statistics pertinent to each model (Table 3)

Prediction model	Statistics: Number of transects (n)	Coefficient of determination (R^2)	Standard error of estimate ($S_{y \cdot x}$)
Forage production weight on unmined areas	83	0.545	356 lbs/acre
Plant cover density on unmined areas	83	0.785	13.1 percent
Forage production weight on mined and revegetated areas			
Native vegetation	44	0.685	380 lbs/acre
Introduced vegetation	33	0.735	547 lbs/acre
Plant cover density on mined and revegetated areas			
Native vegetation	44	0.666	17.5 percent
Introduced vegetation	33	0.615	19.2 percent

Packer, Paul E., Chester E. Jensen, Edward L. Noble, and John A. Marshall. 1982. Models to estimate revegetation potentials of land surface mined for coal in the West. USDA For. Serv. Gen. Tech. Rep. INT-123, 25 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Practical criteria for measuring success of revegetation of land surface mined for coal in the West, namely, the amount of forage produced and the density of plant cover developed, are affected significantly by at least two major climatic factors that are not readily susceptible to alteration (precipitation and growing season length); by three properties of spoil materials that are subject to limited modification through management (potassium, sodium, and pH). Revegetation success is also influenced by seven revegetation treatments, each of which provides at least two management alternatives, and by the age of the vegetation. These characteristics account for from one-half to three-fourths of the total variance in forage production and plant cover density on these revegetated lands.

KEYWORDS: strip mining, surface mining, reclamation, revegetation, production potentials, cover potentials

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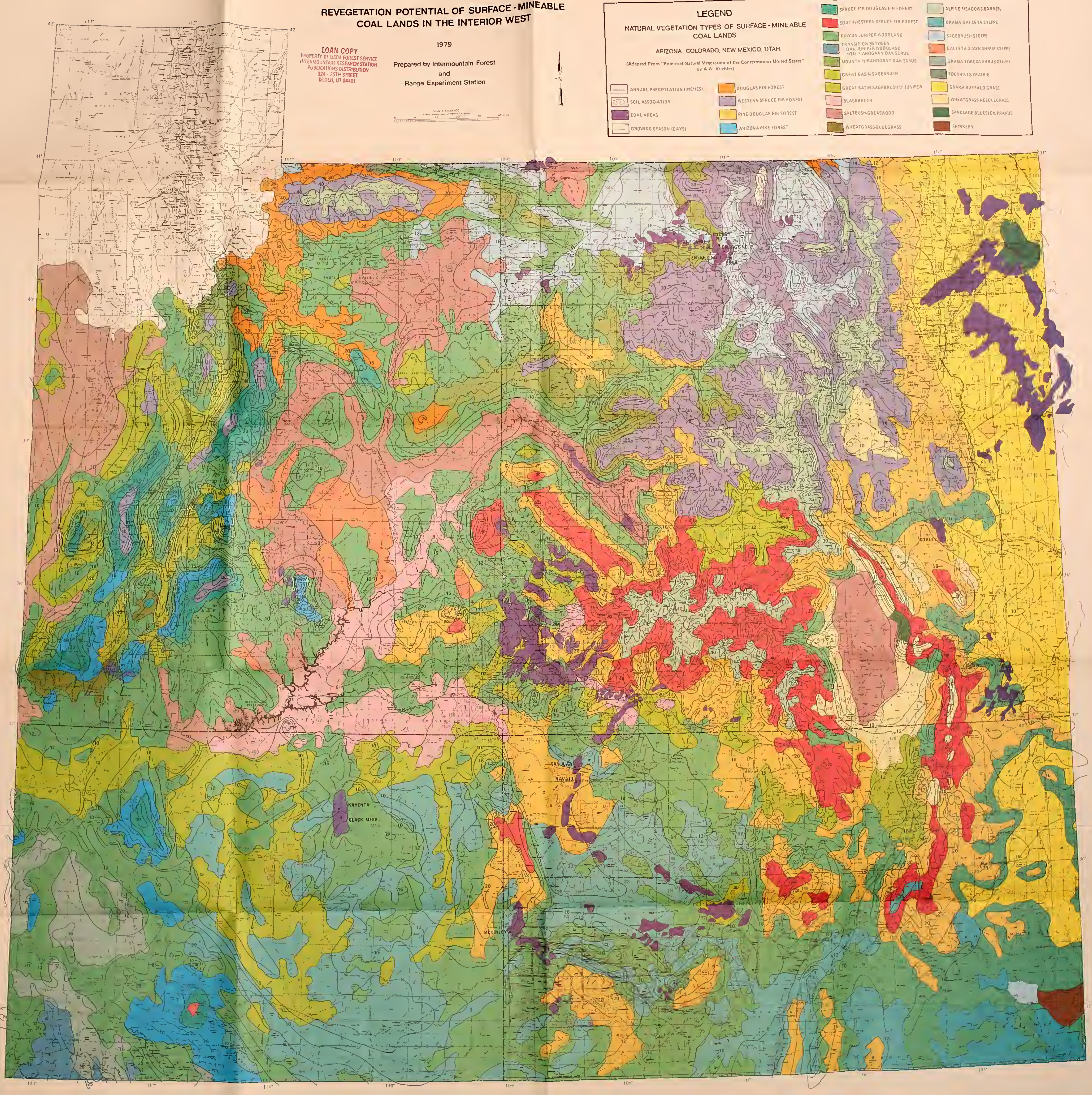
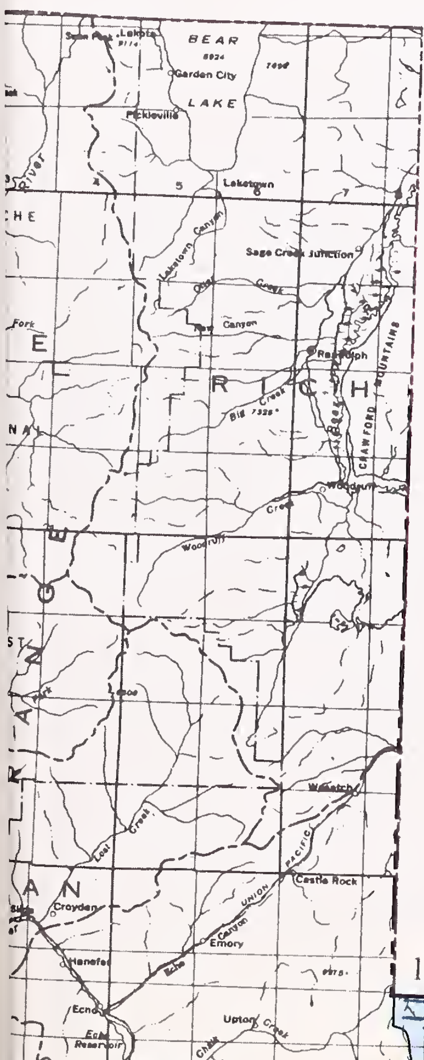
REVEGETATION POTENTIAL OF SURFACE-MINEABLE COAL LANDS IN THE INTERIOR WEST

1979

Prepared by Intermountain Forest and Range Experiment Station



REVEGETATION POTENTIAL OF SURFACE-MIN
COAL LANDS IN THE INTERIOR WEST



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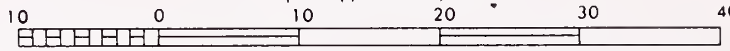
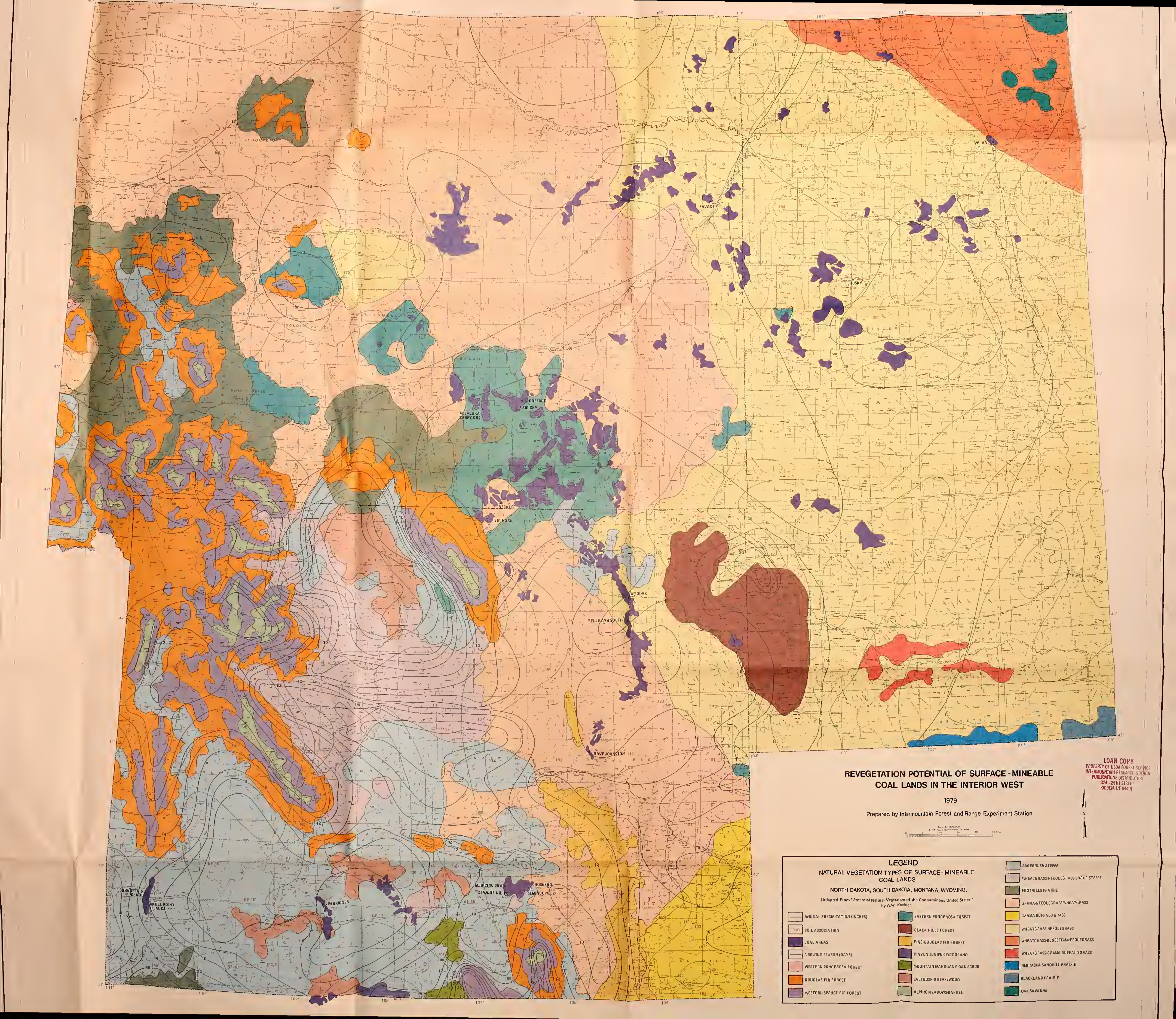
Range Experiment Station

Scale 1:1,000,000
1 inch equals approximately 16 miles



110°

109°



REVEGETATION POTENTIAL OF SURFACE - MINEABLE COAL LANDS IN THE INTERIOR WEST
1979
Prepared by Intermountain Forest and Range Experiment Station
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LEGEND
NATURAL VEGETATION TYPES OF SURFACE - MINEABLE COAL LANDS
NORTH DAKOTA, SOUTH DAKOTA, MONTANA, WYOMING.
(Adapted From "Potential Natural Vegetation of the Conterminous United States" by A.W. Kuchler)
ANNUAL PRECIPITATION (INCHES)
SOIL ASSOCIATION
COAL AREAS
GROWING SEASON (DAYS)
WESTERN PONDEROSA FOREST
DOUGLAS FIR FOREST
WESTERN SPRUCE FIR FOREST
EASTERN PONDEROSA FOREST
BLACK HILLS FOREST
PINE-DOUGLAS FIR FOREST
PINYON-JUNIPER WOODLAND
MOUNTAIN MAHOGANY-OAK SCRUB
SALTBUSH-GREASEWOOD
ALPINE MEADOWS-BARREN
SAGEBRUSH STEPPE
WHEATGRASS-NEEDLEGRASS SHRUB STEPPE
FOOTHILLS PRAIRIE
GRAMA-NEEDLEGRASS-WHEATGRASS
GRAMA BUFFALO GRASS
WHEATGRASS-NEEDLEGRASS
WHEATGRASS-BLUESTEM-NEEDLEGRASS
WHEATGRASS-GRAMA-BUFFALO GRASS
NEBRASKA SANDHILL PRAIRIE
BLACKLAND PRAIRIE
OAK SAVANNA
VELVA
SAVAGE
HUSKY
ROSEBUD
BIG SKY
ABSALOKA (SARPY CR.)
DECKER
BIG HORN
WYODAK
BELLE AYR SOUTH
DAVE JOHNSTON
JIM BRIDGER
MEDICINE BOW
SEMINOE NO. 2
SKULL POINT